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CONVENTIONAL MAGNET COOLING TESTS

S. Lackey

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Measurement of the thermal characteristics of C-, H-, extraction Lambertson, split Lambertson, and EPB dipole magnets have been completed. The following is a synopsis of these results as well as a short description of each magnet and its field characteristics.

The test set up included a Transrex power supply which was on dc or controlled by an astable multivibrator to give an accurate 10 second on 20 second off waveform. The temperature sensors used were Matthey Bishop Thermafilm type 100W47 grade II, which have a thermal response time of less than .2 seconds. The temperatures of the supply and return buses were monitored and plotted by a MAC-16 computer. In some cases more water flow was necessary for adequate cooling and a booster pump was used with the normal switchyard LCW.

C-MAGNET

The C-Magnet consists of two coils; each provides one current path and 2 parallel water paths. The copper used is .2576" square with a .143" diameter hole. For more detailed information regarding the magnet consult drawing No. 0526-ME-23164.

Information regarding the field of a C-Magnet can be found in TM-569 from which Table I has been reproduced here. The 1700 amp tests then would correspond to a field of 31.945 KG-m at the center.

Two separate tests were made, one at 981 amps dc and one at 1700 amps which was on for 10 seconds and off for 20 seconds. Both of these correspond to an rms power of 14.35 kW per coil. It was necessary to increase the available pressure in order to cool the magnets sufficiently. The results of these tests are summarized in Tables II and III.

EXTRACTION LAMBERTSON

The extraction Lambertsons have one coil, consisting of 6 loops, which is 126.25" long. The water as well as the electrical current has only one path. The copper is .46" square with a .255" diameter hole.

In these tests the Lambertson was run at 981 amps dc and pulsed at 1700 amps (10 seconds on 20 seconds off). Both the supply and return temperatures were monitored. The results are summarized in Tables IV and V.

EPB DIPOLE

The EPB Dipole consists of 2 coils each with 16 loops 125.9-inches long. The 2 coils are electrically in series and provide four parallel water paths.

The EPB Dipole is described in TM-434 from which Table VI has been reproduced.

The EPB Dipole was tested at 1900 amps with 10 seconds on and 20 seconds off. The supply and return temperatures were monitored for the top coil and the bottom inside coil. The results of this test are summarized in Table VII.

H-MAGNET

The H-Magnet consists of one coil of .46 inch square copper with a .255-inch diameter hole. The measured dc resistance was 14.6 milliohm.

The magnet was tested at 972 amps dc and 1700 amps for 10 seconds on and 20 seconds off at various pressures and flows. The results are summarized in Tables IX and X. Table VIII was reproduced from TM-569 and includes the field values for an H-Magnet at various currents.

SPLIT LAMBERTSON

The split Lambertson magnets have 2 coils which are in series electrically, but have parallel water paths. Each of the coils is comprised of six turns which are 126" long. The copper used is .46" square with a .25" diameter hole.

The magnet was tested at 1660 amperes with normal LCW flow and at 2000 amperes with a flow of 2.65 gpm. The same 10 seconds on and 20 seconds off ramp was used. The results of the tests are summarized in Table XII.

Field data for split Lambertsons can be found in TM-435 from which the information in Table XI comes.

Table XII is a summary of the calculated results compared to the measured results. The method used to calculate the expected temperature rise was to consider the power to be dissipated in each core and use equation A.

$$\Delta T = \frac{\text{Power in kW}}{(4.2\ \text{J/cal})(\text{flow in } \ell/\text{s})(1\ \text{cal/cm}^3\,{}^\circ\text{C})} \qquad \text{A)}$$

To determine the expected pressure differential for a given flow, equation B was used to get the Reynolds number. This was

$$R_e = 3160 \frac{Q}{\nu d} \qquad \text{B)}$$

where Q = flow in gallons per minute

ν = kinematic viscosity in centistokes

d = internal diameter of water passage in inches.

Then equation C was used to calculate the expected pressure differential.

$$\Delta P = 2.16 \times 10^{-4} \frac{F \ell \rho Q^2}{d^5} \qquad \text{C)}$$

where F is the friction factor

ρ is the weight density of water in pounds/ft^3

ℓ is the length of the conductor in feet.

The time constants were calculated by considering the total heat capacity of the copper and the water and dividing this into the power to be dissipated. This gave a number for the temperature rise per sec if the process were linear. The time constant was then determined. A second iteration was then performed to include the heat capacity of the additional water which would have flowed through the magnet during this time which yielded the time constant in Table XIII.

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Reference

1. Crane Technical Paper No. 410, Flow of fluids Through Valves, Fittings, and Pipe; p. A-25.

TABLE I

$\int$Bdl at the Center of C-Magnet*

I (amps)	$\int$Bdl (kG-m)
200	3.86
400	7.88
600	11.82
800	15.75
1000	19.67
1200	23.55
1400	27.23
1600	30.49
1800	33.40
2000	36.09
2200	38.59
2400	40.89

*Information from TM-569.

TABLE II

C-MAGNET AT 981 AMPS DC*

	T_O	T_F
Top Coil Supply	33.74°C	35.
Top Coil Return	33.8°C	80.93°C
Bottom Coil Supply	33.8°C	35.9°C
Time Constant	19.04 seconds	

*Water flow of 2.4 gpm; pressure differential of 123 psi.

TABLE III

C-MAGNET AT 1700 AMPS FOR 10 SECONDS ON 20 SECONDS OFF*

	T_O	T_F
Top Coil Supply	33.7°C	37.6°C
Top Coil Return	33.7°C	92.0°C
Bottom Coil Supply	33.7°C	37.2°C
Bottom Coil Return	33.8°C	92.0°C

*Water flow of 2.9 gpm, pressure differential of 178 psi.

TABLE IV

EXTRACTION LAMBERTSON AT 981 AMPS DC*

	T_O	T_F
Supply	31.5°C	32°C
Return	29.1°C	48.6°C
Time Constant	138 Seconds	

*Water flow of 1.6 gpm, pressure differential of 111 psi.

TABLE V

EXTRACTION LAMBERTSON AT 1700 AMPS FOR 10 SECONDS ON 20 SECONDS OFF*

	T_O	T_F
Supply	31.5°C	32°C
Return	31°C	49.8°C

*Water flow of 1.6 gpm, pressure differential of 111 psi.

TABLE VI

Measurements of $\int B_y dz$ and B_y as a function of current for an EPB dipole (AircoTemescal Magnet #71)

Current (A)	$\int B_y dz$ (kG-m)	Current (A)	B_y (kG)
0	--	0	<10 gauss
199.9	6.43	200.1	2.101
400.0	12.82	400.0	4.208
600.4	19.26	600.5	6.307
800.2	25.60	800.3	8.340
999.9	31.85	1000.4	10.43
1200.1	37.63	1199.9	12.34
1399.8	41.64	1400.5	13.65
1600.1	44.92	1600.2	14.72
1687.0	46.17*	1689.1	15.16
1700.2	46.35	--	--
1800.1	47.68	1800.7	15.67
1900.3	48.90	--	--
2000.5	50.05	--	--

*This is not a measured point.

TABLE VII

EPB DIPOLE AT 1900 AMPS FOR 10 SECONDS ON 20 SECONDS OFF*

	T_O	T_F
Top Coil Supply	29.3°C	32.3°C
Top Coil Return	31.5°C	67.4°C
Bottom Inside Coil Supply	29.3°C	32.3°C
Bottom Inside Coil Return	31.5°C	68.2°C
Time Constant	262.5 seconds	

*Water flow of 2.0 gpm, pressure differential of 30 psi.

TABLE VIII

$\int Bdl$ AT THE CENTER OF H-MAGNET*

I (Amps)	$\int Bdl$ (kG-M)
200	6.02
400	12.14
600	18.35
800	24.50
1000	30.74
1200	36.83
1400	42.57
1600	47.43
1800	51.61
2000	55.22
2200	58.25
2400	60.72

*Reproduced from TM-569.

TABLE IX

H-MAGNET PULSED AT 1700 AMPS FOR 10 SECONDS ON AND 20 SECONDS OFF*

	T_O	T_F
Supply	33.8°C	-
Return	33.8°C	90.15°C

*Water flow of 1.05 gpm, pressure differential of 100 psi.

TABLE X

H-MAGNET PULSED AT 1700 AMPS FOR 10 SECONDS ON AND 20 SECONDS OFF*

	T_O	T_F
Supply	35.0°C	-
Middle	35.0°C	60.2°C
Return	35.0°C	83.98°C
Time Constant	105 seconds	

*Water flow of 1.29 gpm, pressure differential of 145 psi.

TABLE XII

SPLIT LAMBERTSON PULSED FOR 10 SECONDS ON 20 SECONDS OFF

	T_O (°C)	T_F (°C)	FLOW (gpm)	CURRENT (amperes)
Supply	27.6	28.5	1.35	1660
			2.65	2000
Return	27.3	55.0	1.35	1660
	29.6	52.4	2.65	2000

TABLE XI

MEASUREMENTS OF $\int$Bdl ON LAMBERTSON SEPTUM MAGNETS*

Field (kG-M)

Current (Amps)	13A	14A	15A	16B
0	0.052	-	-	-
200	3.184	3.196	3.182	3.173
400	6.373	6.355	6.349	6.333
600	9.555	9.537	9.538	9.511
800	12.711	12.737	12.700	12.684
1000	15.888	15.884	15.870	15.855
1200	19.050	19.048	19.055	19.020
1400	22.201	22.196	22.196	22.187
1600	25.332	25.360	25.333	25.309
1800	28.434	28.444	28.442	28.426
2000	31.421	31.435	31.445	31.480

*Reproduced from TM-435.

TABLE XIII

MAGNET	$\Delta T_{(calc.)}$ (°C)	$\Delta T_{(meas.)}$ (°C)	$T_{c(calc.)}$ (sec.)	$T_{c(meas.)}$ (sec.)	$\Delta P_{(meas.)}$ (psi)	$\Delta P_{(calc.)}$ (psi)	FLOW (gpm)
EPB Dipole	35.76	36.7	253.9	262.5	30	22	2.0
		35.9					
C-Magnet	50	58.3	14.07	19.4	104	91.3	2.16
		58.2					
H-Magnet	50.74	56.35	109.2	105	100	105	1.05
	41.14	48.98			145	153	1.29
Extraction Lambertson	15.9	18.8	106.25	138	111	114	1.6
Split Lambertson	35.03	27.7	44.95	46	28	27.6	1.35
	25.9	22.75			100	93	2.65